

A dynamic graphic featuring a globe with several aircraft models orbiting it. The globe is set against a background of blue and green streaks, suggesting high-speed travel or aerodynamic flow. The text "NASA AERONAUTICS" is overlaid on the globe.

NASA AERONAUTICS

Drag and Aircraft Design

Simple Hands-On Inquiry Activities

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Background

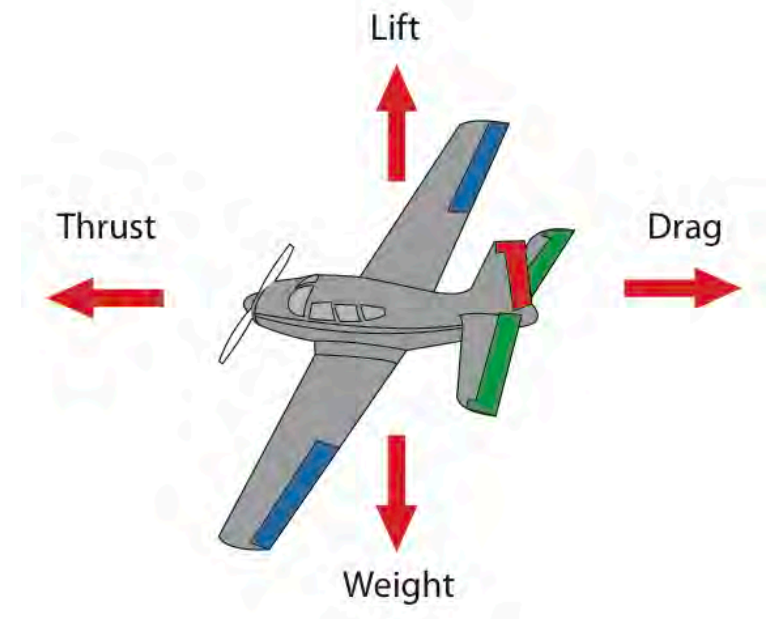
NASA Aeronautics works to solve the many challenges that exist in the nation's airspace system. In fact, every U.S. aircraft flying today and every U.S. air traffic control tower uses NASA-developed technology in some way.

This document includes four very simple "station" activities that can be used to teach students about some of NASA Aeronautics' themes of ongoing research, namely advancing green aviation, reducing flight delays, revisiting supersonic flight, and designing future aircraft. Learn more about these themes at <http://www.nasa.gov/aeronautics>

Nearly all of these research themes share a single commonality – an understanding of **drag** and effects on aircraft. In its simplest form, drag is defined as the resistive force on an object as it attempts to move through a fluid (such as air or water). Drag acts opposite to the direction of motion of the object that is moving.

The purpose of these activities is to help students develop a conceptual understanding of drag, its causes, and its effect on the motion of an object. Students are also asked to consider, very simply, how engineers might design an aircraft to perform a given task (such as fast or slow flight, travel at high or low altitudes, or gliding with high or low finesse).

In fact, NASA engineers are currently working on future aircraft designs that meet many of these needs. Because aircraft experience a variety of conditions in flight, engineers are now also considering how an aircraft might respond, changing its shape so it can fly in the best way possible. To see an example of NASA-designed future aircraft, visit the Down to Earth Future Aircraft Gallery: <http://www.nasa.gov/content/down-to-earth-future-aircraft-0>



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Objectives

- Define drag.
- Describe the effect of drag on the motion of various objects of different mass, shape, size, and movement through fluids of different viscosity.
- Hypothesize some reasons for the cause of drag.

Standards Addressed

NGSS Forces and Interactions

- K-PS2-1. Plan and conduct an investigation to compare the effects of different strengths or different directions of pushes and pulls on the motion of an object.
- K-PS2-2. Analyze data to determine if a design solution works as intended to change the speed or direction of an object with a push or a pull.*
- 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
- 3-PS2-2. Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.
- MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

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NGSS Science and Engineering Practices

- Asking questions (for science) and defining problems (for engineering).
- Developing and using models.
- Planning and carrying out investigations.
- Analyzing and interpreting data.
- Providing constructive explanations (for science) and designing solutions (for engineering).

NGSS Cross-Cutting Principles

- Patterns
- Cause and Effect
- Structure and Function
- Systems and System Models

Materials

Standard Coffee Filters

Paper Muffin Cups

10-gallon Coffee Filters (optional)

Stapler

Marker

Mass Balance

Golf Balls

Ping Pong Balls

Corn Syrup

Translucent, long containers

Marbles

Print-outs for Stations

Activities

Note: In advance of all activities, ensure that all stations are set up as described in the lesson. *

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Define Drag

Before beginning with these activities, it is important that students first develop a conceptual understanding of force. Most students understand forces to be either a “push” or a “pull;” and while sufficient for this activity, it can be beneficial to first provide students with a thorough understanding of force vectors.

To help students understand drag, provide students with a demonstration that will result in cognitive dissonance – a surprise that, for most, will elicit misconceptions about their understanding of objects falling through a fluid (such as air).

Begin by showing students a golf ball and a ping-pong ball. Ask students to compare their mass, shape, size, and the kind of fluid that surrounds them (air). Students should find that the only *major* difference between the two is that the golf ball is much heavier than the ping-pong ball. Then, ask the students to predict the motion of the two balls if they are released from the same height at the same time. Most students will say that the heavy one will fall faster. Before demonstrating, ask students to prepare to listen for the balls as they hit the ground, and to watch for the collision with the ground as well. Allow the single demonstrator (teacher or student) to drop the two objects from the same height at the same time. Students will often be shocked to find that, on average, the balls hit the ground at the same time!



Then, prepare to show students a single regular coffee filter, and a stack of multiple coffee filters. Again, the only major difference between the two items is that the single coffee filter weighs much less than the stack of coffee filters. Ask students to again predict how their motions will be different. Upon dropping the single and set of coffee filters, students will see that there is a *major difference* in the time it takes to drop the single and the set of coffee filters.

In both cases (golf ball vs. ping-pong ball, and single vs. stack of coffee filters), the only difference between them was the mass. So, the question remains: why do the coffee filters behave differently than the balls?

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Instead of answering this question outright, ask students to explain what could have caused the single coffee filter to fall so slowly. Most older children with an understanding of forces will be able to describe that there was some resistance from the air (**drag**) that was pushing opposite the motion of the falling object. Once this definition has been elaborated, encourage students to move to the four stations and to determine the effect of drag on objects of various masses, shapes, sizes, and movement through fluids of different viscosity.

Describe the effect of drag on the motion of various objects of different mass, shape, size, and movement through fluids of different viscosity.

Prepare the following stations in advance of having students split into small groups. Then, allow students to rotate through the stations in small groups until they have accomplished each task.

Mass

1. Place the station paper with the RED text box that reads, "Drop coffee filters of different masses. How does this affect their motions?"
2. Prepare sets of regular coffee filters of different masses (1, 2, 3, 4, and 9 coffee filters). Ensure that the stacks stay together by stapling them at the base. Label the stacks with the number of coffee filters in the stack.
3. Encourage students to work together to drop the coffee filters at the same time, and to describe any differences in motion that they perceive.
4. For more advanced students, ask students to determine how much higher a stack with double the mass must be placed in order to fall in the same amount of time as a single-unit stack.



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5. After answering the question, ask students to read and discuss in their small groups, "What's the big idea?" and "How do engineers use this idea in their designs?"

Shape

1. Place the station paper with the GREEN text box that reads, "Drop coffee filters of different shapes. How does this affect their motions?"
2. Prepare quantities of single coffee filters: **some** single coffee filters used for control tests, and other single coffee filters that have been set aside for students to change their shape (without changing mass). Students may crumple or fold the test coffee filters as they see fit.
3. Encourage students to work together to drop the coffee filters at the same time, and to describe any differences in motion that they perceive.
4. For more advanced students, ask students to determine if they can change or drop the coffee filters in such a way that the modified coffee filter (with the changed shape) actually takes more time to fall than the unmodified coffee filter.
5. After answering the question, ask students to read and discuss in their small groups, "What's the big idea?" and "How do engineers use this idea in their designs?"



Size

1. Place the station paper with the ORANGE text box that reads, "Drop coffee filters of different sizes. How does this affect their motions?"
2. Prepare quantities of 10-gallon coffee filters (optional; these are readily available online), standard coffee filters, and paper



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muffin tins that all display different sizes, but same shape and same mass. To ensure that the sets have the same mass, use an electronic or triple-beam balance, and label the stacks so that students know they have equal mass. Use a staple to keep the stacks together (the mass of the staple is likely negligible; or, include its mass on the balance when massing the stacks).

3. Encourage students to work together to drop the coffee filters and muffin tins at the same time, and to describe any differences in motion that they perceive.
4. For more advanced students, allow the students to prepare the stacks of regular coffee filters or muffin tins themselves. In this case, provide the balance at their disposal.
5. After answering the question, ask students to read and discuss in their small groups, "What's the big idea?" and "How do engineers use this idea in their designs?"



Fluid

1. Place the station paper with the BLUE text box that reads, "Drop marbles through different fluids. How does this affect their motions?"
2. Prepare four or five long and thin transparent bottles and fill them with fluids of different viscosity. (For the bottles, check the store's "travel" section for clear shampoo bottles.) To prepare liquids of different viscosities, place different amounts of corn syrup and water into the bottles and shake well. Ensure that one of the bottles is filled with 100% corn syrup, and that another is filled with 100% water. The remaining bottles should be filled with different percentages of corn syrup and water. Drop a marble into each bottle, and then close the bottle tightly. (Optional:



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3. Use clear tape to seal off the bottles so they are not intentionally or inadvertently opened).
4. Encourage students to work together to invert the bottles to determine

what is different about the fluids in each bottle, and how they know. Ask students to compare the marble traveling through the corn syrup and water mixture to aircraft travelling through low-altitude or high-altitude atmosphere, where the atmosphere is more and less thick, respectively.

5. For more advanced students, ask them to rank the viscosities of the fluids in the tubes. Ask students to consider a method to quantify the viscosity of the fluids in each tube. (Consider providing a stopwatch, and encouraging them to observe the fast-moving marbles as they roll down a gentle incline, without fully inverting the bottles).
6. After answering the question, ask students to read and discuss in their small groups, "What's the big idea?" and "How do engineers use this idea in their designs?"

Hypothesize Reasons for Cause of Drag

After all students have had the opportunity to participate in the activities at each station, ask all students to re-convene to share their outcomes. In general, students will find:

- As mass increases, coffee filters tend to fall faster (although, this is not generalizable, given what was seen with the balls).
- As shape gets smaller, coffee filters tend to fall faster.
- As size gets smaller, coffee filters tend to fall faster.
- As viscosity of the fluid increases, marbles tend to fall more slowly.

Ask students to consider if any of these statements are generalizable (could be applied nearly to any object moving through a fluid):

- Students might mention that some very large objects (like the 10-gallon coffee filter) are simply not stable, and won't fall in a uniform way.

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- Students should mention that coffee filters and the balls did not seem to behave the same. Mass seemed to make a difference in the falling rate of the coffee filters, but not the balls.

Encourage students to consider what actually causes drag, and why the same air particles that affect the coffee filters don't seem to interact with the balls in the same way. Consider discussing the meaning of aerodynamic and non-aerodynamic shapes, and how scientists visualize these.

In the case of the coffee filters, air particles are more likely to get trapped and collide with the surface of the coffee filter, while they tend to move around the balls because of their shape. Dropping balls on the surface of the Earth is very similar to dropping balls on the surface of the moon; although they will accelerate more quickly on Earth, compared to one another they will land on both the Earth and on the moon in nearly the same time. Encourage students to develop their own models, given what they know about air, and encourage students to visualize their concepts on whiteboards or posters.

Drag is not a simple concept. Unlike surface friction, air particles often interact in unexpected, chaotic ways, and a single air particle does not need to directly touch an object in order to be influenced by an object as it moves through a fluid.

For more information about drag, please refer to NASA's Beginner's Guide to Aerodynamics: <https://www.grc.nasa.gov/WWW/k-12/airplane/bga.html>

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Drop coffee filters of different **masses**.

How does this affect their **motions**?



What's the big idea?

When there is air drag present, heavier items tend to fall more quickly than lighter items. Heavier items take longer to reach their final speed when there is air, because they have more momentum.

How do engineers use this idea in their designs?

It requires more energy (fuel and money) to keep heavier airplanes in the sky. NASA engineers work to make airplanes both strong and lightweight. The X-48B is a NASA test airplane that used new composite materials to make it as light as possible.

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Drop coffee filters of different **shapes**.

How does this affect their **motions**?



What's the big idea?

Some shapes experience less drag because their shapes allow air particles to flow around them more easily.

How do engineers use this idea in their designs?

Drag can prevent airplanes from moving quickly through the air. NASA engineers work to make the fastest airplanes in the world, like this futuristic design in the image. NASA has designed airplanes that have gone at least 6.7 times the speed of sound.

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Drop coffee filters of different **sizes**.

How does this affect their **motions**?



What's the big idea?

Objects with large surfaces have more area that can collide with air particles and cause drag.

How do engineers use this idea in their designs?

Drag isn't always a bad thing in aerospace engineering. NASA engineers use drag to help them slow down fast-moving objects with parachutes. Pictured to the left is the capsule from the Orion mission as it falls from space back to Earth.

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Drop marbles through different **fluids**.

How does this affect their **motions**?



What's the big idea?

Some fluids are more viscous ("stickier") than others. Stickier fluids cause an object to experience more drag. Air might not seem very thick, but the atmosphere near the ground is much thicker than the atmosphere near the edge of space.

How do engineers use this idea in their designs?

NASA engineers have to design for both thick and thin air. On the left, NASA engineers have designed high-altitude aircraft, such as ER-2, with long wings to fly in thin air.